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Prospects of biodiesel production from vegetable oils in India

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Abstract

The world is confronted with the twin crises of fossil fuel depletion and environmental degradation. The indiscriminate extraction and consumption of fossil fuels have led to a reduction in petroleum reserves. Alternative fuels, energy conservation and management, energy efficiency and environmental protection have become important in recent years. The increasing import bill has necessitated the search for liquid fuels as an alternative to diesel, which is being used in large quantities in transport, agriculture, industrial, commercial and domestic sectors. Biodiesel obtained from vegetable oils has been considered a promising option.

In this paper, an attempt has been made to review the work done on biodiesel production and utilization, resources available, process(es) developed/being developed, performance in existing engines, environmental considerations, the economic aspect, and advantages in and barriers to the use of biodiesel.

Keywords: Vegetable oils; Transesterification; Biodiesel; Methanol; Glycerol; Methyl esters; Triglycerides

Contents

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1. Introduction

In recent times, the world has been confronted with an energy crisis due to depletion of resources and increased environmental problems. The situation has led to the search for an alternative fuel, which should be not only sustainable but also environment friendly. For developing countries, fuels of bio-origin, such as alcohol, vegetable oils, biomass, biogas, synthetic fuels, etc. are becoming important. Such fuels can be used directly, while others need some sort of modification before they are used as substitute of conventional fuels. As per an estimate, India consumed about 40.34 million tons of diesel in 2000–2001, which was 43.2% of the total consumption of petroleum products [1], and two-thirds of

the demand was met by import costing about Rs. 200 billion. With an expected growth rate of diesel consumption of more than 14% per annum, shrinking crude oil reserves and limited refining capacity, India will have to depend heavily on imports of crude.

From the point of view of protecting the global environment and the concern for long-term supplies of conventional diesel fuels, it becomes necessary to develop alternative fuels comparable with conventional fuels. Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sectors for the generation of power/mechanical energy, and the substitution of even a small fraction of total consumption by alternative fuels will have a significant impact on the economy and the environment. Of the alternative fuels, biodiesel obtained from vegetable oils holds good promises as an eco-friendly alternative to diesel fuel.

Literature shows that a number of studies of acid and base catalyzed transesterification have been carried out. Freedman and Pryde [29] and Kusy [30] achieved more than 95% fatty ester yield in 1 h using alkaline catalyst. Freedman et al. [17,24] found that for maximum ester yield, the requisites are acid value less than 1 mg KOH/g, oil with moisture free alcohol and vegetable oil. Nye and Southwell [14] have studied the effect of catalyst on methyl and ethyl esters of rapeseed oil at room temperature. Boocock et al. [31] developed a new method, which produced methyl ester much faster. Schwab et al. [32] and Liu [33] compared acid and base catalysts. Nye et al. [14] compared base and acid catalysts to produce methyl esters from used frying oil. Kusdiana and Saka [34] have studied the kinetics of transesterification of rapeseed oil to biodiesel fuel using supercritical methanol.

The present paper is an attempt to review the possibilities of using neat vegetable oils and biodiesel, the processes available, fuel characteristics, performance analysis and economic analysis of biodiesel production.

2. Alternative diesel fuels

Alternative fuels should be easily available, environment friendly and techno-economically competitive. One of such fuels is triglycerides (vegetable oils/animal fats) and their derivatives. Vegetable oils, being renewable, are widely available from a variety of sources and have low sulphur contents close to zero, and hence cause less environmental damage (lower greenhouse effect) than diesel. Besides, vegetable oils and their derivatives are produced widely in the country for food and other purposes.

2.1. Triglyceride as diesel fuels

The use of vegetable oils, such as palm, soya bean, sunflower, peanut, and olive oil, as alternative fuels for diesel engines dates back almost nine decades, but due to the rapid decline in crude oil reserves, it is again being promoted in many countries. Depending upon the climate and soil conditions, different countries are looking for different types of vegetable oils as substitutes for diesel fuels. For example, soya bean oil in the US, rapeseed and sunflower oils in Europe, palm oil in South-east Asia (mainly Malaysia and Indonesia) and coconut oil in the Philippines are being considered. The production of oil

Table 1
Production of oilseeds in 2002–2003 in India

Oilseed	Production (million tons)		Total oil availability (million tons)	% Recovery	Oil cost (Rs. per ton)
	World	India			
Soya bean	123.2	4.30	0.63	17	4300
Cottonseed	34.3	4.60	0.39	11	3200
Groundnut	19.3	4.60	0.73	40	6200
Sunflower	25.2	1.32	0.46	35	5360
Rapeseed	34.7	4.30	1.37	33	5167
Sesame	2.5	0.62	–	–	6800
Palm kernels	4.8	–	–	–	–
Copra	4.9	0.65	0.42	65	3035
Linseed	2.6	0.20	0.09	43	–
Castor	1.3	0.51	0.21	42	–
Niger	0.8	0.08	0.02	30	–
Rice bran	–	–	0.60	15	2000
Total	253.6	21.18	4.92	–	

seeds, percentage oil recovery and their respective cost are given in Table 1 [2,3], which indicates that the use of vegetable oils as sources of diesel would require more efforts to increase the production of oil seeds and to develop new and more productive plant species with high yield of oil.

Besides, some species of plants yielding non-edible oils, e.g. jatropha, karanji and pongamia may play a significant role in providing resources. Both these plants may be grown on a massive scale on agricultural/degraded/waste lands, so that the chief resource may be available to produce biodiesel on 'farm scale'.

2.2. Chemical compositions

Vegetable oils, also known as triglycerides, have the chemical structure given in Fig. 1 comprise of 98% triglycerides and small amounts of mono- and diglycerides. Triglycerides are esters of three molecules of fatty acids and one of glycerol and contain substantial amounts of oxygen in their structure. The fatty acids vary in their carbon chain length and in the number of double bonds.

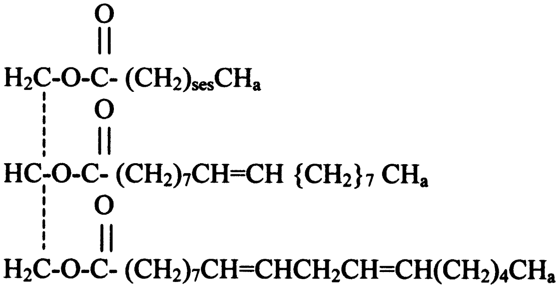


Fig. 1. Structure of a typical triglyceride molecule.

Table 2
Chemical structure of common fatty acids

Name of fatty acid	Chemical name of fatty acids	Structure (*xx*:*y*)	Formula
Lauric	Dodecanoic	12:0	$C_{12}H_{24}O_2$
Myristic	Tetradecanoic	14:0	$C_{14}H_{28}O_2$
Palmitic	Hexadecanoic	16:0	$C_{16}H_{32}O_2$
Stearic	Octadecanoic	18:0	$C_{18}H_{36}O_2$
Arachidic	Eicosanoic	20:0	$C_{20}H_{40}O_2$
Behenic	Docosanoic	22:0	$C_{22}H_{44}O_2$
Lignoceric	Tetracosanoic	24:0	$C_{24}H_{48}O_2$
Oleic	*cis*-9-Octadecenoic	18:1	$C_{18}H_{34}O_2$
Linoleic	*cis*-9,*cis*-12-Octadecadienoic	18:2	$C_{18}H_{32}O_2$
Linolenic	*cis*-9,*cis*-l2,*cis*-15-Octadecatrienoic	18:3	$C_{18}H_{30}O_2$
Erucle	*cis*-13-Docosenoic	22:1	$C_{32}H_{42}O_2$

xx indicates number of carbons, and *y* number of double bonds in the fatty acid chain.

Different types of oils have different types of fatty acids. The empirical formula and structure of various fatty acids present in vegetable oils are given in Table 2 [4].

2.3. Properties of vegetable oils as fuel

The fuel properties of vegetable oils as listed in Table 3 [2,3] indicate that the kinematics viscosity of vegetable oils varies in the range of 30–40 cSt at 38 °C. The high viscosity of these oils is due to their large molecular mass in the range of 600–900, which is about 20 times more higher than that of diesel fuel. The flash point of vegetable oils is very high (above 200 °C). The volumetric heating values are in the range of 39–40 MJ/kg, as compared to diesel fuels (about 45 MJ/kg). The presence of chemically bound oxygen in vegetable oils lower their heating values by about 10%. The cetane numbers are in the range of 32–40.

Table 3
Properties of vegetable oils

Vegetable oil	Kinematic viscosity at 38 °C (mm^2/s)	Cetane no. (°C)	Heating value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density (kg/l)
Corn	34.9	37.6	39.5	−1.1	−40.0	277	0.9095
Cottonseed	33.5	41.8	39.5	1.7	−15.0	234	0.9148
Crambe	53.6	44.6	40.5	10.0	−12.2	274	0.9048
Linseed	27.2	34.6	39.3	1.7	−15.0	241	0.9236
Peanut	39.6	41.8	39.8	12.8	−6.7	271	0.9026
Rapeseed	37.0	37.6	39.7	−3.9	−31.7	246	0.9115
Safflower	31.3	41.3	39.5	18.3	−6.7	260	0.9144
Sesame	35.5	40.2	39.3	−3.9	−9.4	260	0.9133
Soya bean	32.6	37.9	39.6	−3.9	−12.2	254	0.9138
Sunflower	33.9	37.1	39.6	7.2	−15.0	274	0.9161
Palm	39.6	42.0	–	31.0	–	267	0.9180
Babassu	30.3	38.0	–	20.0	–	150	0.9460
Diesel	3.06	50	43.8	–	−16	76	0.855

2.4. Utilization of vegetable oils as fuels

2.4.1. Use of vegetable oils as diesel fuel

It has been found that this neat vegetable oils can be used as diesel fuels in conventional diesel engines, but this leads to a number of problems related to the type and grade of oil and local climatic conditions. The injection, atomization and combustion characteristics of vegetable oils in diesel engines are significantly different from those of diesel. The high viscosity of vegetable oils interferes with the injection process and leads to poor fuel atomization. The inefficient mixing of oil with air contributes to incomplete combustion, leading to heavy smoke emission, and the high flash point attributes to lower volatility characteristics. These disadvantages, coupled with the reactivity of unsaturated vegetable oils, do not allow the engine to operate trouble free for longer period of time. These problems can be solved, if the vegetable oils are chemically modified to biodiesel, which is similar in characteristics to diesel.

2.4.2. Use of biodiesel

Biodiesel is defined as the monoalkyl esters of long-chain fatty acids derived from renewable feedstock, such as vegetable oil or animal fats, for use in compression–ignition engines [5]. Biodiesel has been reported as a possible substitute or extender for conventional diesel and is comprised of fatty acid methyl/ethyl esters, obtained from triglycerides by transesterification with methanol/ethanol, respectively. Biodiesel is compatible with conventional diesel and both can be blended in any proportion. Preparation of biodiesel from sunflower oil, used frying oil, jatropha oil, karanji (pongamia) oil, etc. as a source of triglycerides has been reported.

2.5. Fuel properties of biodiesel

The properties of biodiesel and diesel fuels, as given in Table 4 [9–13], show many similarities, and therefore, biodiesel is rated as a strong candidate as an alternative to diesel. This is due to the fact that the conversion of triglycerides into methyl or ethyl esters through

Table 4
Properties of biodiesel from different oils

Vegetable oil methyl esters (biodiesel)	Kinematic viscosity (mm^2/s)	Cetane no.	Lower heating value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density (kg/l)
Peanut	4.9	54	33.6	5	–	176	0.883
Soya bean	4.5	45	33.5	1	−7	178	0.885
Babassu	3.6	63	31.8	4	–	127	0.875
Palm	5.7	62	33.5	13	–	164	0.880
Sunflower	4.6	49	33.5	1	–	183	0.860
Tallow	–	–	–	12	9	96	–
Diesel	3.06	50	43.8	–	−16	76	0.855
20% biodiesel blend	3.2	51	43.2	–	−16	128	0.859

the transesterification process reduces the molecular weight to one-third, reduces the viscosity by about one-eighth, and increase the volatility marginally. Biodiesel contains 10–11% oxygen (w/w), thereby enhancing the combustion process in an engine. It has also been reported that the use of tertiary fatty amines and amides can be effective in enhancing the ignition quality of the biodiesel without having any negative effect on its cold flow properties. However, starting problems persist in cold conditions. Further, biodiesel has low volumetric heating values (about 12%), a high cetane number and a high flash point. The cloud points and flash points of biodiesel are 15–25 °C higher than those of diesel.

3. Process of biodiesel production

3.1. Simple transesterification reaction

Transesterification of vegetable oils with simple alcohol has long been the preferred method for producing biodiesel. In general, there are two methods of transesterification. One method simply uses a catalyst and the other is without a catalyst. The former method has a long history of development and the biodiesel produced by this method is now available in North America, Japan and some western European countries.

3.2. Chemistry of transesterification reaction

The overall transesterification reaction [6] is given by three consecutive and reversible equations as below:

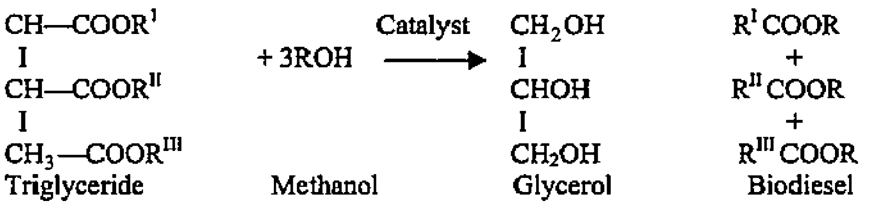
$$\text{Triglyceride} + \text{ROH} \overset{\text{catalyst}}{\Longleftrightarrow} \text{Diglyceride} + \text{R}^{\text{I}}\text{COOR}$$

$$\text{Diglyceride} + \text{ROH} \overset{\text{catalyst}}{\Longleftrightarrow} \text{Monoglyceride} + \text{R}^{\text{II}}\text{COOR}$$

$$\text{Monoglyceride} + \text{ROH} \overset{\text{catalyst}}{\Longleftrightarrow} \text{Glycerol} + \text{R}^{\text{III}}\text{COOR}$$

The first step is the conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides, and of monoglycerides to glycerol, yielding one methyl ester molecule per mole of glyceride at each step [7,8].

The overall chemical reaction of the transesterification process is:



where R^{I}, R^{II} and R^{III} are long-chain hydrocarbons which may be the same or different with $R = -CH_3/C_2H_5$.

As seen above, the transesterification is an equilibrium reaction in which excess alcohol is required to drive the reaction close to completion. Fortunately, the equilibrium constant favors the formation of methyl esters such that only a 5:1 molar ratio of methanol:triglycerides is sufficient for 95–98% yield of ester. It might be anticipated that in such a system, glycerol would play a major role in achieving conversions close to 100%. Several catalysts were tried for the purpose of transesterification by several workers, e.g. magnesium, calcium oxides and carbonates of basic and acidic macro-reticular organic resin, alkaline alumina, phase transfer catalysts, sulphuric acids, *p*-toluene sulphonic acid, and dehydrating agents as co-catalysts [14]. The catalysts reported to be effective at room temperature were alkoxides and hydroxides [15].

During methanolysis, two distinct phases are present as the solubility of the oil in methanol is low and the reaction mixture needs vigorous stirring. Optimum reaction conditions for the maximum yield of methyl esters have been reported to be 0.8% (based on weight of oil) potassium hydroxide catalyst and 100% excess methanol at room temperature for 2.5 h. Glycerol phase separation does not occur when <67% of the theoretical amount of methanol is used. The excess methanol, however, is removed by distillation. Traces of methanol, KOH, free fatty acids (FFAs), chlorophyll, etc. go into the glycerin phase, which can be processed in two stages. Glycerin of 90–95% purity is obtained in the first stage and of 98% purity in the second stage. The basic process schematic of biodiesel production is given in Fig. 2. The energetics have indicated that about 50 kW of electricity per ton of biodiesel is required, of which 60–70% is consumed for the production of glycerin. The process requires mixing of vegetable oil with a mixture prepared by dissolving KOH catalyst in methanol and heating at 70 °C with stirring for 1 h. The mixture is allowed to settle under gravity. The glycerin, being heavier, settles down in the bottom layer and the upper layer constitutes the biodiesel (esters). The glycerin is separated and the esters are washed

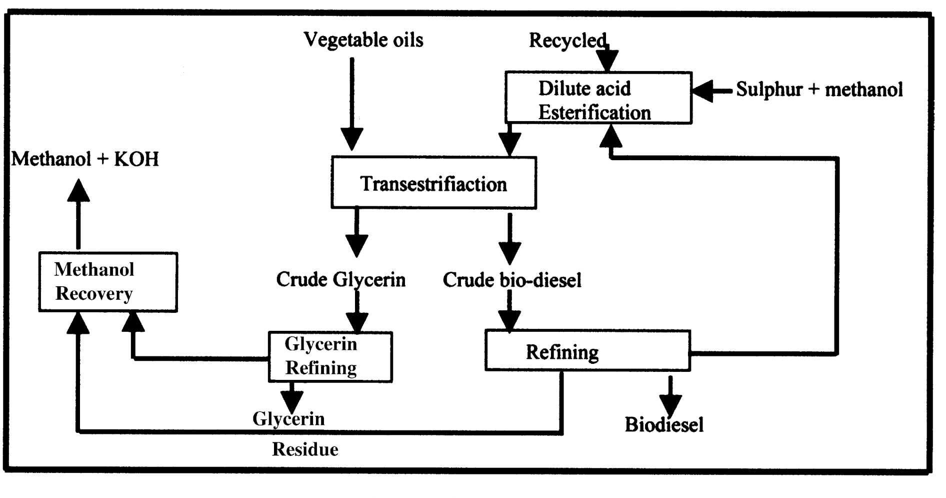


Fig. 2. Basic technology.

with water for catalyst recovery. The biodiesel layer is finally dried using silica gel and it is now ready for blending with diesel in various proportions for engine operation. The blend, for convenience, is referred to as B_{xx}, where XX indicates the amount of biodiesel in percentage in the blend (i.e. B-20 blend is 20% biodiesel and 80% diesel).

4. Process variables

The most important variables that influence the transesterification reaction are:

- Reaction temperature.
- Ratio of alcohol to vegetable oil.
- Catalyst.
- Mixing intensity.
- Purity of reactants.

4.1. Reaction temperature

The literature has revealed that the rate of reaction is strongly influenced by the reaction temperature. However, the reaction is conducted close to the boiling point of methanol (60–70 °C) at atmospheric pressure for a given time. Such mild reaction conditions require the removal of free fatty acids from the oil by refining or preesterification. Therefore, degummed and deacidified oil is used as feedstock [17]. Pretreatment is not required if the reaction is carried out under high pressure (9000 kPa) and high temperature (240 °C), where simultaneous esterification and transesterification take place with maximum yield obtained at temperatures ranging from 60 to 80 °C at a molar ratio of 6:1 [11,18,19].

4.2. Ratio of alcohol to oil

Another important variable is the molar ratio of alcohol to vegetable oil. As indicated earlier, the transesterification reaction requires 3 mol of alcohol per mole of triglyceride to give 3 mol of fatty esters and 1 mol of glycerol. In order to shift the reaction to the right, it is necessary to either use excess alcohol or remove one of the products from the reaction mixture. The second option is usually preferred for the reaction to proceed to completion. The reaction rate was found to be highest when 100% excess methanol was used. A molar ratio of 6:1 is normally used in industrial processes to obtain methyl ester yields higher than 98% (w/w) [17].

4.3. Catalysts

Alkali metal alkoxides are found to be more effective transesterification catalysts compared to acidic catalysts. Sodium alkoxides are the most efficient catalysts, although

KOH and NaOH can also be used. Transmethylation occurs in the presence of both alkaline and acidic catalysts [20]. As they are less corrosive to industrial equipment, alkaline catalysts are preferred in industrial processes. A concentration in the range of 0.5–1% (w/w) has been found to yield 94–99% conversion to vegetable oil esters [11,21], and further increase in catalyst concentration does not affect the conversion but adds to extra cost, as the catalyst needs to be removed from the reaction mixture after completion of the reaction.

4.4. Mixing intensity

It has been observed that during the transesterification reaction, the reactants initially form a two-phase liquid system. The mixing effect has been found to play a significant role in the slow rate of the reaction. As phase separation ceases, mixing becomes insignificant. The effect of mixing on the kinetics of the transesterification process forms the basis for process scale-up and design.

4.5. Purity of reactants

Impurities in the oil affect the conversion level considerably. It is reported that about 65–84% conversion into esters using crude vegetable oils has been obtained as compared to 94–97% yields refined oil under the same reaction conditions [17]. The free fatty acids in the crude oils have been found to interfere with the catalyst. This problem can be solved if the reaction is carried out under high temperature and pressure conditions.

5. Supercritical methanol transesterification

The simple transesterification process discussed above is confronted with two problems, i.e. the process is relatively time consuming and it needs separation of the catalyst and saponified impurities from the biodiesel. The first problem is due to the phase separation of the vegetable oil/methanol mixture, which may be dealt with by vigorous stirring. These problems are not faced in the supercritical methanol method of transesterification. This is perhaps due to the fact that the tendency of two-phase formation of vegetable oil/methanol mixture is not encountered and a single phase is found due to decrease in the dielectric constant of methanol in the supercritical state. As a result, the reaction was found to be complete in a very short time within 2–4 min. Further, since no catalyst is used, the purification on biodiesel is much easier, trouble free and environment friendly [22].

The result of transesterification of rapeseed oil in the supercritical methanol method has indicated that at temperature of 239 °C and pressure of 8.09 MPa, glycerol and methyl esters are obtained as the principal products [22]. Encinar et al. [23] have reported the optimal molar ratio of methanol to cynara oil to be between 4.05 and 5.57, beyond which either the catalytic transesterification is incomplete or glycerin separation becomes very difficult. However, a 98% conversion of vegetable oils to methyl esters

could be achieved at the molar ratio of 6. When the oil contains a large amount of free fatty acids, a higher molar ratio even up to 45 can be used. It has also been observed that with decrease in molar ratio to a theoretical value of 3, the conversion decreased to 82% [24].

It has further been observed that under supercritical conditions, the conversion rate of rapeseed oil varies with molar ratio such that a higher molar ratio of MeOH results in increased yield of methyl esters and decreased yields in intermediate products. The study, therefore, concluded that complete conversion with 95% yield took place with a molar ratio of methanol of 42 [22] at a critical temperature of 350 °C, whereas a lower molar ratio of 6 or less results in incomplete conversion of rapeseed oil to methyl esters.

A study on the effect of temperature at a fixed molar ratio of methanol of 42 indicates that at temperatures of 200 and 230 °C, the yield of methyl esters was reported to be about 68 and 70%, respectively, after a reaction time of 1 h [25]. At a temperature of 270 °C, the conversion rate is still low, perhaps due to the stability of the supercritical condition (pressure 14 MPa). However, at 300 °C, 80% conversion to methyl ester was observed in 240 s. Even at a higher temperature of 400 °C, the reaction is almost completed within 120 s, though the decomposition reaction starts taking place due to the thermal degradation of triglyceride molecules at such a high temperature.

6. Performance of biodiesel in diesel engine

Conventional IC engines can be operated with biodiesel without major modifications [26]. In comparison to diesel, the higher cetane number of biodiesel results in shorter ignition delay and longer combustion duration and hence results in low particulate emissions and minimum carbon deposits on injector nozzles. It is reported that if an engine is operated on biodiesel for a long time, the injection timing may be required to be readjusted for achieving better thermal efficiency [10,16]. Various blends of biodiesel with diesel have been tried, but B-20 has been found to be the most appropriate blend. Further studies have revealed that biodiesel blends lead to a reduction in smoke opacity, and emission of particulates, unburnt hydrocarbons, carbon dioxide and carbon monoxide, but cause slightly increase in nitrous oxide emissions [28]. It is noteworthy that all the blends have a higher thermal efficiency than diesel and so give improved performance. The effect of the concentration of ester blend on peak thermal efficiency is given in Fig. 3.

The figure shows that the ester blend with a concentration of 20% biodiesel gave maximum improvement in peak thermal efficiency, minimum brake specific energy consumption and minimum smoke opacity. Hence, B-20 was recommended as the optimum blend for long-term engine operation [16].

7. Environmental considerations

In view of environmental considerations, biodiesel is considered ‘carbon neutral’ because all the carbon dioxide released during consumption had been sequestered from the atmosphere for the growth of vegetable oil crops. Studies have shown that

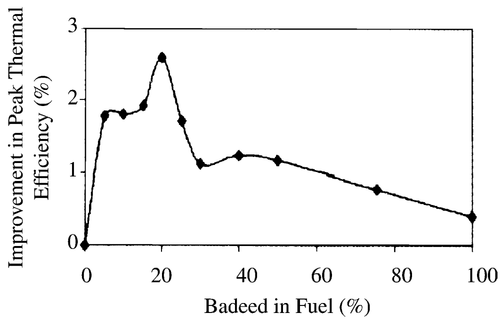


Fig. 3. Improvement in peak thermal efficiency vs. concentration of biodiesel blend.

the combustion of 1 l of diesel fuel leads to the emission of about 2.6 kg of CO_2 against 1 kg of CO_2/kg of biodiesel [27], so the use of biodiesel may directly displace this amount of CO_2 when used in engines. The combustion of biodiesel has been reported to emit lesser pollutants compared to diesel. The emission of SO_2, soot, CO, hydrocarbons (HC, polyaromatic hydrocarbons (PAH), and aromatics is given in Fig. 4 [28], which indicates that the engine exhaust contains no SO_2, and shows decreasing emissions of PAH, soot, CO, HC and aromatics.

The NO_x emissions are reported to be in the range between $\pm 10\%$ as compared to diesel depending on engine's combustion characteristics.

8. Economic feasibility of biodiesel

India has rich and abundant resources of edible and non-edible oilseeds, the production of which can be stepped up manifolds if the government provides incentives to farmers for production of biodiesel. The economic feasibility of biodiesel depends on the price of crude petroleum and the cost of transporting diesel over long distances to remote areas. It is a fact that the cost of diesel will increase in future owing to the increase in its demand and limited supply. Further, the strict regulations on the aromatic and sulphur contents of diesel fuels will make diesel costlier, as the removal of aromatics from distillate fractions needs costly processing equipment and continuous high operational cost as large amounts

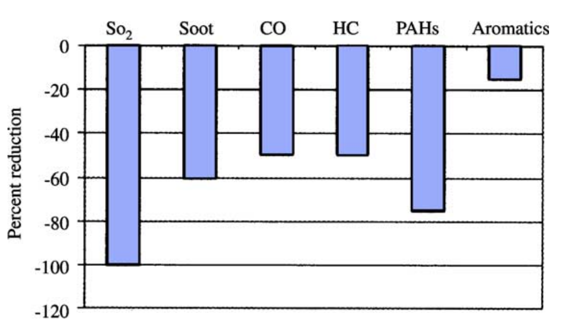


Fig. 4. Lower emissions of biodiesel compared with petrodiesel.

Table 5
Total cost per litre of biodiesel from various vegetable oils

Vegetable oil	Cost of vegetable oil per litre (Rs.)	Cost of biodiesel per litre (Rs.)
Groundnut	58	48.28
Mustard	48	38.60
Sesame	64	54.00
Coconut	28	18.61
Safflower	60	50.26
Soya bean	40	30.26
Sunflower	50	40.26
Linseed	23	13.56
Pongamia oil (non-edible oil)	18	10.50
Diesel		22.00

of hydrogen are required for ring saturation. Similarly, reducing the sulphur content is also a big challenge for the industries. Currently, the production of methyl or ethyl esters from edible oils is much more expensive than that of diesel fuels due to the relatively high costs of vegetable oils (about four times the cost of diesel in India). Methyl esters produced from such oils cannot compete economically with diesel fuels unless they are granted protection from tax levies. Under such conditions, there is a need to explore alternate feedstocks for the production of biodiesel.

An economic analysis for the production of biodiesel using different types of edible and non-edible oils has been carried out and the results are reported in Table 5.

The analysis indicates that linseed oil has the least cost (Rs. 13.56 per litre) and sesame oil has the maximum cost (Rs. 54.00 per litre). The analysis has considered the cost of a plant (Rs. 1,174,000) with an installed capacity 136,500 per year and 10% depreciation. The operating cost and by-product cost per year are Rs. 4,018,002 and 2,296,000, respectively, with a 10 year life of the plant [29]. Table 5 indicates that the cost of biodiesel produced from pongamia oil is the least, i.e. Rs.10.50, followed by linseed oil (Rs. 13.50) and coconut oil (Rs. 18.61) as compared to diesel (Rs. 22) per litre.

The cost can be reduced further if we consider non-edible oils, used frying oils and acid oils instead of edible oils. Non-edible oils from sources such as neem, mahua, pongamia, karanji, babassu, jatropha, etc. are easily available in many parts of the world including India, and are very cheap compared to edible oils. With the mushrooming of fast food centers and restaurants in India, it is expected that considerable amounts of used frying oil will be discarded which can be diverted for biodiesel production, and thus may help reduce the cost of water treatment in the sewerage system and assisting in the recycling of resources. Acid oil, which is cheaper than both raw and refined oils, is a major by-product of the alkali refining industries and is a potential raw material for making biodiesel.

9. Institutions working on biodiesel in India

Various research institutes are doing R&D on various aspects of resource production, process development and utilization in engines as well as environmental aspects of the use

of biodiesel. The following institutions are working in this area:

SI no.	Name of institute/organization	Area of work
1	Indian Institute of Science, Bangalore (Karnataka)	Promoting cultivation of pongamia
2	Central Salt and Marine Research Institute, Bhavnagar (Gujarat)	Cultivation of jatropha
3	Indian Institutes of Petroleum, Dehradun (Uttaranchal)	Performance testing of transport buses cultivation of jatropha, neem and karanji
4	Delhi College of Engineering, New Delhi	Production
5	Harcourt Butler Technological Institute, Kanpur	Production
6	Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee	Kinetics of transesterification
7	Indian Oil Corporation Limited, Faridabad	Process development
8	Bapuji Institute of Engineering and Technology, Davangere	Engine application

10. Conclusion

Alternate fuels for diesel engines have become increasingly important due to diminishing petroleum reserves and awareness of the increased environmental consequences of emissions from petroleum-fuelled engines. A number of studies have shown that triglycerides (vegetable oils/animal fats) hold promise as alternative fuels for diesel engines. However, the high viscosity, low volatility and poor cold flow properties of triglycerides, which result in severe engine deposits, injector coking and piston ring sticking, have prevented them from being used directly in diesel engines. One way to improve the fuel properties of triglycerides is the catalytic transesterification of triglycerides with alcohols to form monoalkyl esters of long-chain fatty acids, and another method is the supercritical method of producing biodiesel, which is quite similar to hydrocarbon-based diesel fuels in its main characteristics and provides similar engine performance with low emission levels unlike fossil fuels. Economic feasibility study shows that the biodiesel obtained from non-edible oils is cheaper than that from edible oils.

11. Recommendations

- Vegetable oils and biodiesel hold great promise as substitutes of diesel in existing diesel engines without any modification. The partial or full replacement of diesel with

biodiesel will relieve the pressure on existing diesel oil resources as well as conserve a lot of diesel fuel, thereby saving substantial money.

- Edible and non-edible oil and animal fats can be used to produce biodiesel. Non-edible oils find great promise as biodiesel, and hence there is a need to grow high yielding non-edible oil seed crops on arable and non-arable lands.
- There are two methods for the production of biodiesel—simple transesterification and the supercritical methanol transesterification method. The latter method has greater scope for the production of biodiesel than the former, because the yield and product quality are superior and the time consumed in conversion is much less. There is, thus, good scope for the development of the supercritical transesterification method.
- Techno-economic feasibility study indicates that the cost of biodiesel derived from linseed oil is the cheapest (Rs. 13.56 per litre) and that from sesame oil is the costliest (Rs. 54 per litre), compared to the diesel cost of Rs. 22.00 per litre. It is expected that the production of biodiesel from vegetable oils will be technically and economically more feasible provided the cost of vegetable oils comes down substantially in the country.

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